JET Status, Programme, Operating Experience and Statistics

S. Ciattaglia[1], P.Bayetti[1], M. Cox[2], F. Scaffidi-Argentina[1]

EFDA-CSU and UKAEA Culham

presented by F. Scaffidi-Argentina

IEA Task 5: Component reliability data for Fusion

1 - EFDA CSU at JET
2 - UKAEA, JET Operator, Culham

Outline

- JET under EFDA
- JET programme 2000 - 2004
  - JET Operation 2000 - 2001
  - JET Plan 2002 - 2004
- Operating experience and Statistic analysis
- Future work
- Conclusions

JET Under EFDA

- The European Fusion Development Agreement covers three areas:
  - Technology Activities
  - The Collective use of the JET Facilities
  - The European Contribution to International collaborations (ITER)
- The JET Implementing Agreement defines the contractual arrangements for Scientific and Technical (S/T) tasks for Experiments, Enhancements and Fusion Technology Activities at JET
- Funding from EURATOM, Associates, Joint Fund and UKAEA
- International Collaborations (~10% during C1-C4 exp. campaigns)
- IEA agreement on Co-operation on the Large Tokamak Facilities
- IEA agreement related to TEXTOR and ASDEX-Upgrade
- EU-US and EU-RF Bilateral Agreement

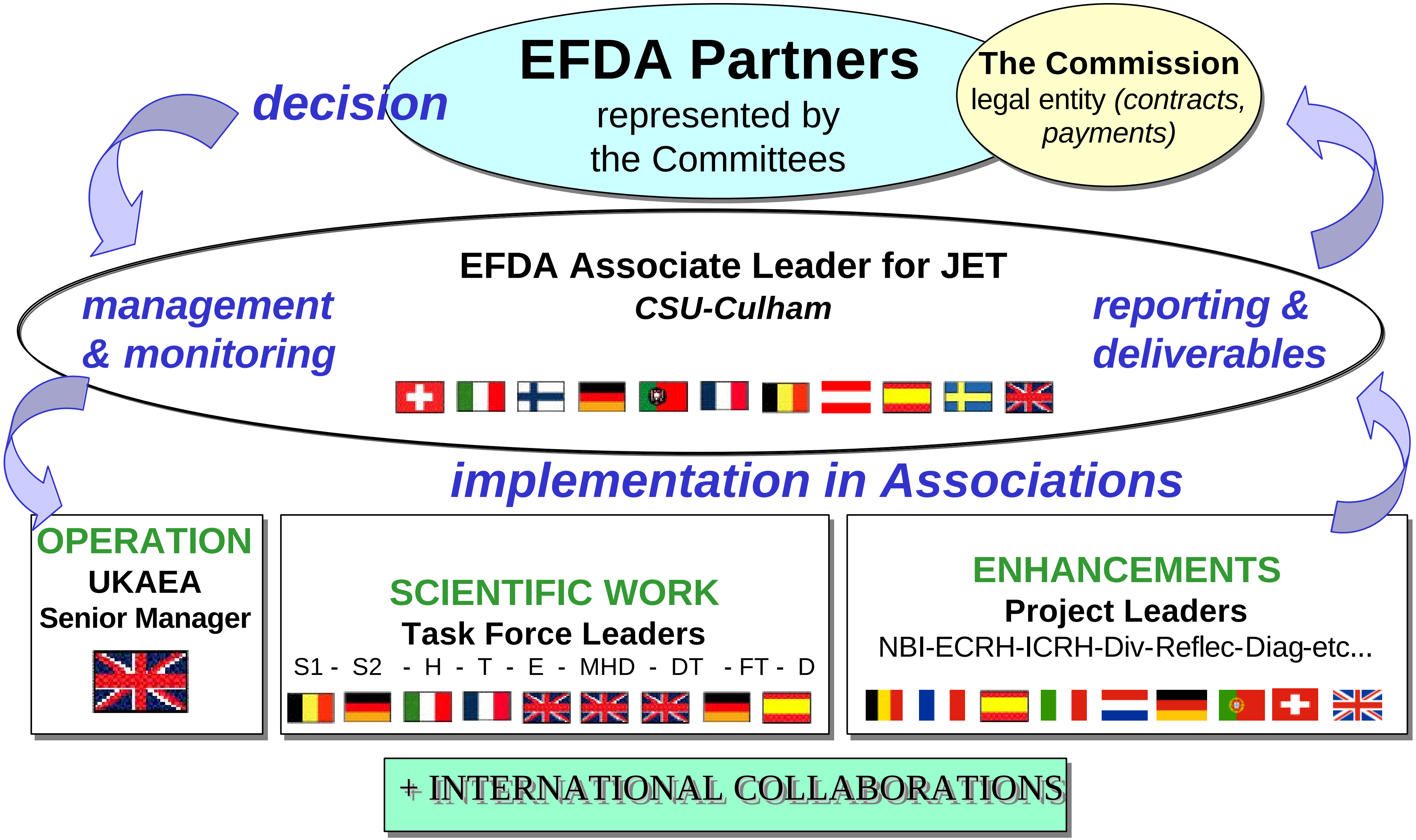
JET Under EFDA

JET under EFDA is organised as "user facility"

The JET Operating Contract is conferred to UKAEA

"Key Players" are:

- ***EFDA Associate Leader for JET***
  - overall supervision and co-ordination of activities at JET
  - contractual management of the JOC
  - management of a Close Support Unit
- ***UKAEA Senior Manager***
  - responsible for the operation and the safety of the JET Facilities
  - responsible for neutrons, activation and contamination monitoring
  - installation and commissioning of approved enhancements
  - makes reasonable endeavours to meet general operational requirements


EFDA Partners
represented by
the Committees
The Commission
legal entity (contracts, payments)
decision
EFDA Associate Leader for JET
CSU-Culham
management & monitoring
reporting & deliverables
implementation in Associations
OPERATION
UKAEA
Senior Manager
SCIENTIFIC WORK
Task Force Leaders
S1 - S2 - H - T - E - MHD - DT - FT - D
ENHANCEMENTS
Project Leaders
NBI-ECRH-ICRH-Div-Reflec-Diag-etc...
+ INTERNATIONAL COLLABORATIONS

Associated Laboratories, parties to EFDA

1- EURATOM : KEY ACTION FUSION Associated Laboratories, parties to EFDA

Euratom - Belgian State
(Brussels) - (Mol)

Euratom - CEA
TORE SUPRA (Caderache)

Euratom - CIEMAT
TJ-II (Madrid)

Euratom - Conf. Suisse
TCV - SULTAN
(Lausanne) - (Villigen)

Euratom - DCU
(Dublin) - (Cork)

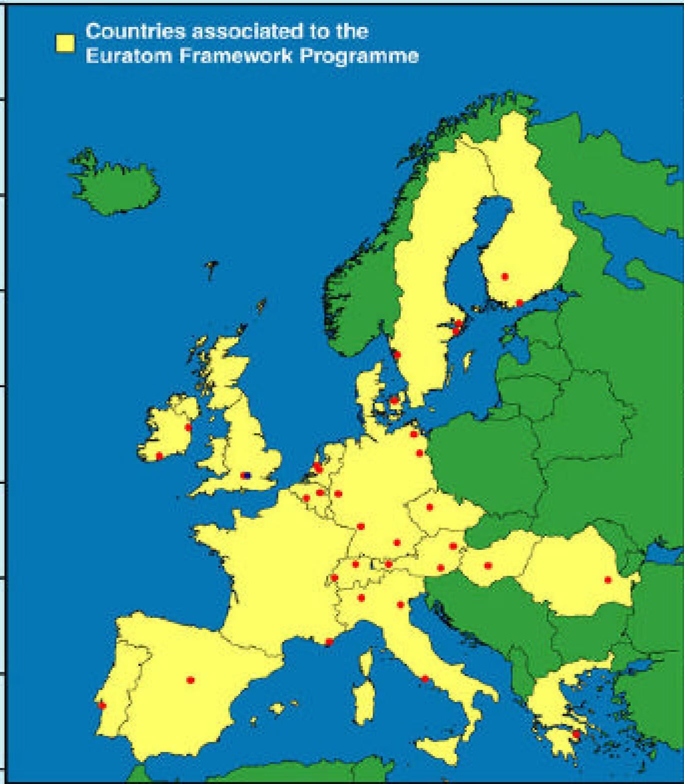
Euratom - ENEA
FTU - RFX
(Frascati) - (Milan) - (Padua)

Euratom - FOM
(Petten) - (Nieuwegein)

Euratom - FZJ
TEXTOR (Jülich)

Euratom - FZK
TOSKA (Karlsruhe)

Euratom - Greece
(Athens) - (Herakloin) - (Ioannina)



• **JET Facilities**
JET (Abingdon)

Euratom - HAS
(Budapest)

Euratom - IPP
Asdex Upgrade Wendelstein 7-AS
(Garching)
Wendelstein 7-X
(Greifswald) - (Berlin)

Euratom - IPP.CR
CASTOR (Prague)

Euratom - IST
ISTTOK (Lisbon)

Euratom - NASTI
(Bucharest)

Euratom - NFR
EXTRAP T2
(Stockholm) (Göteborg) (Studsvik)

Euratom - ÖAW
(Vienna) - (Graz) - (Innsbruck)

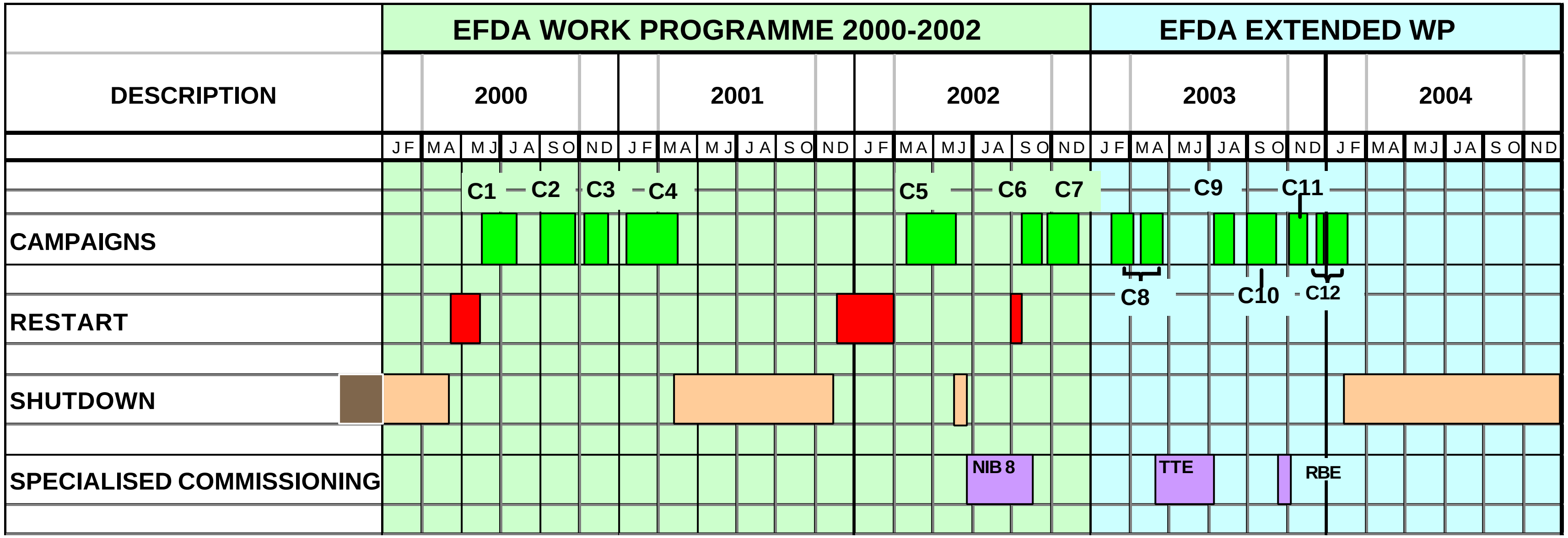
Euratom - RISØ
RISØ (Roskilde)

Euratom - TEKES
(Helsinki) - (Tampere)

Euratom - UKAEA
Compass - MAST - JET
(Culham)

EUROPEAN FUSION DEVELOPMENT AGREEMENT

JET Programme 2000 - 2004



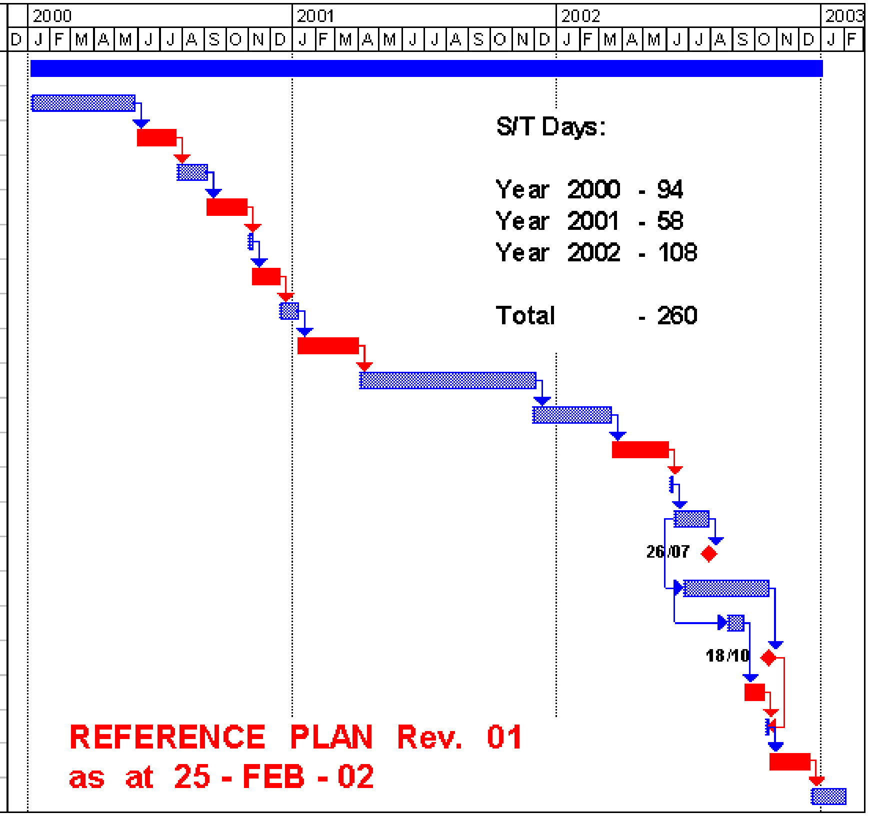
TOTAL DAYS IN PERIOD :-	2000-2002	2003-2004
CAMPAIGNS	262	150
MAINTENANCE	71	26
SHUTDOWNS	234	228
RESTARTS	126	0
SPECIALISED COMMISSIONING	85	71

Nota Bene: 2003 planning is still preliminary

EFDA EUROPEAN FUSION DEVELOPMENT AGREEMENT JET

JET Operation 2000-2001

ID	Task Name	Dur	Start	Finish
1	JET programme 2000-2002	749 d	04/01/00	31/12/02
2	Shutdown & restart programme [2000]	101 d	03/01/00	26/05/00
3	Operation - Campaign C1 [36 S/T ops days]	38 d	31/05/00	21/07/00
4	Intervention	28 d	24/07/00	01/09/00
5	Operation - Campaign C2 [38 S/T ops days]	40 d	04/09/00	27/10/00
6	Maintenance period	5 d	30/10/00	03/11/00
7	Operation - Campaign C3 [20 ops S/T days]	26 d	06/11/00	11/12/00
8	Standby period	19 d	12/12/00	05/01/01
9	Operation - Campaign C4 [58 ops S/T days]	60 d	08/01/01	30/03/01
10	Shutdown [2001]	168 d	02/04/01	30/11/01
11	Restart [2001-2002]	73 d	26/11/01	15/03/02
12	Operation - Campaign C5 [49 ops S/T days]	52 d	18/03/02	31/05/02
13	Break (Jubilee & Bank Holiday)	5 d	03/06/02	07/06/02
14	Shutdown maintenance period	35 d	10/06/02	26/07/02
15	Torus Hall closed for Operation	0 d	26/07/02	26/07/02
16	Complete NIB 8 (incl 3w restart prior to C6)	85 d	24/06/02	18/10/02
17	Restart period	15 d	22/08/02	13/09/02
18	NIB8 project completed	0 d	18/10/02	18/10/02
19	Operation - Campaign C6 [20 ops S/T days]	20 d	16/09/02	11/10/02
20	Standby period	5 d	14/10/02	18/10/02
21	Operation - Campaign C7 (39 ops S/T days)	40 d	21/10/02	13/12/02
22	Christmas Break	35 d	16/12/02	31/01/03



JET Operation 2000 - 2001

Main Topics during C1 - C4: May 2000- March 2001

- Transport and confinement in ELMy H-mode reactor prototype plasmas
- ITB dependence on plasma shaping. ITBs with Significant Electron Heating
- LHCD coupling studies - ICRF CD assessment
- ITB dependence on magnetic shear and flow shear
- Towards full CD and steady-state operation.
- Impurity seeding in different plasmas
- Gas scan at high triangularity and plasma beta
- JET - ASDEX Upgrade confinement identity experiments
- Characterisation of the Mark IIGB Divertor (with Septum)
- Scenario Development for Long Pulse Operation
- ICRH Scenario Development for ITER and JET-EP
- Comparison Studies in Helium - Carbon Migration Studies using C13D4
- Disruption Studies (including mitigation)

JET Operation 2000 - 2001

2001 Shutdown: 31 March 2001 (end of C4) - till 26 Nov. 2001

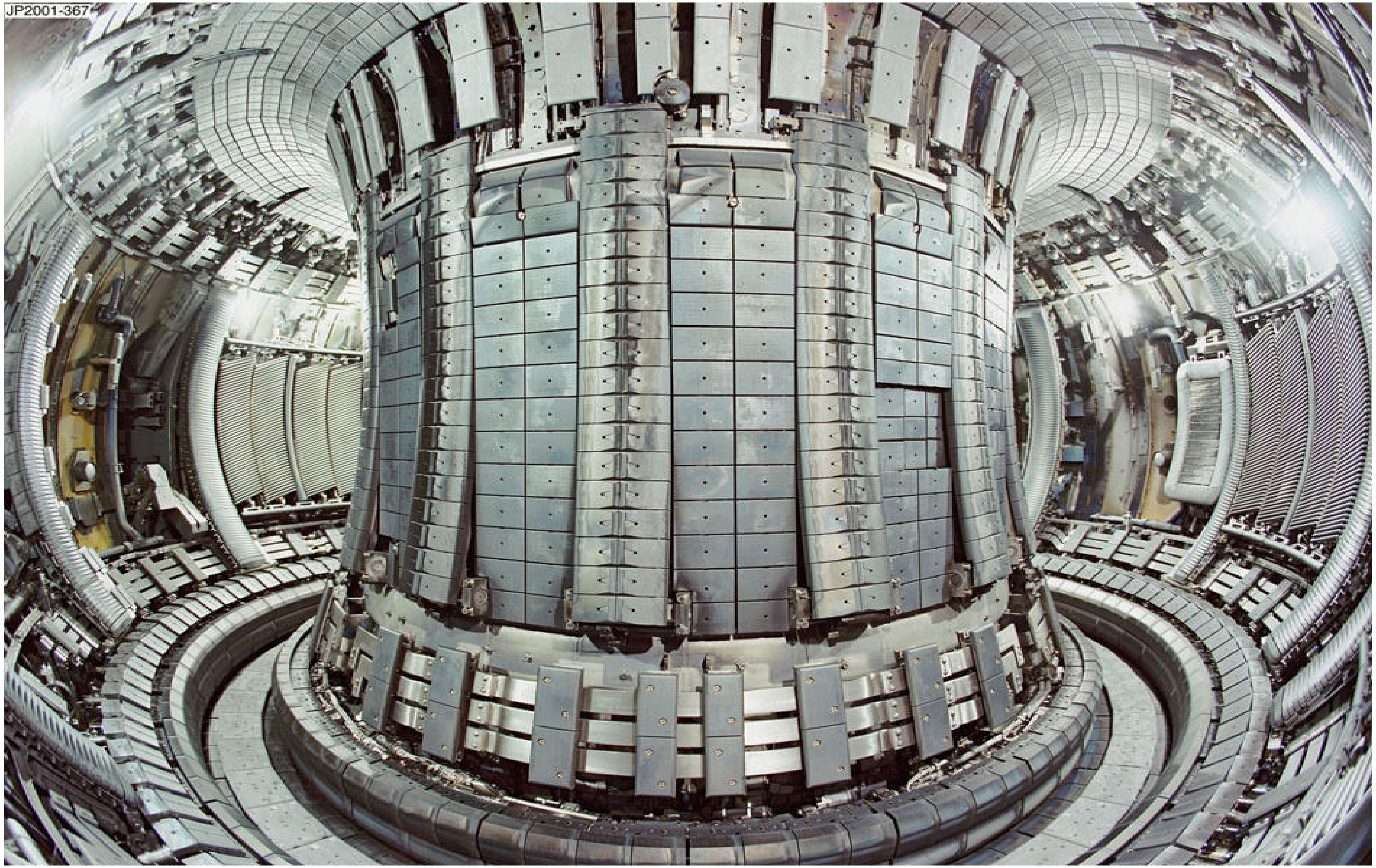
- Removal of MkII-GB Divertor Septum and Dome
- Replacement of TF and Divertor Freon coolant with new coolant
- 11 new / upgraded diagnostics
- Improved Real-Time Control and Extreme Shape Controller
- In-vessel wiring test, removal of flakes and dust, upper inner wall protection reinforcement, halo current coils installation
- NIB8 upgrade project
- NIB4 magnet and NB test bed repair (unplanned)

Main Milestone (Pump-down 26 November) successfully achieved with all planned task completed

Restart: 27 Nov 2001 - 18 March 2002 (beginning of C5)

- **2 weeks of delay** (Vacuum leaks, Cryo-plant and NIB PS problems)

MkII-GB Divertor after removal of the Septum (November 2001)



JET Plan 2002 - 2004

New capabilities of JET facilities for experimental campaigns of year 2002

- Closed **Mark IIGB divertor** configuration **without septum**
- **Increase in NB power (7.5 MW)** after the completion of the Octant 8 Upgrade (8 improved PINIs, 130kV/60A in deuterium for C7)
- **New or improved diagnostics** (i.e. error field correction coils, edge LIDAR Thomson scattering, reciprocating probes, quartz micro-balance, reflectometer, high time resolution pellet spectrometer, and MSE upgrade)
- **New pellet extruder and pellet track** (for C7)

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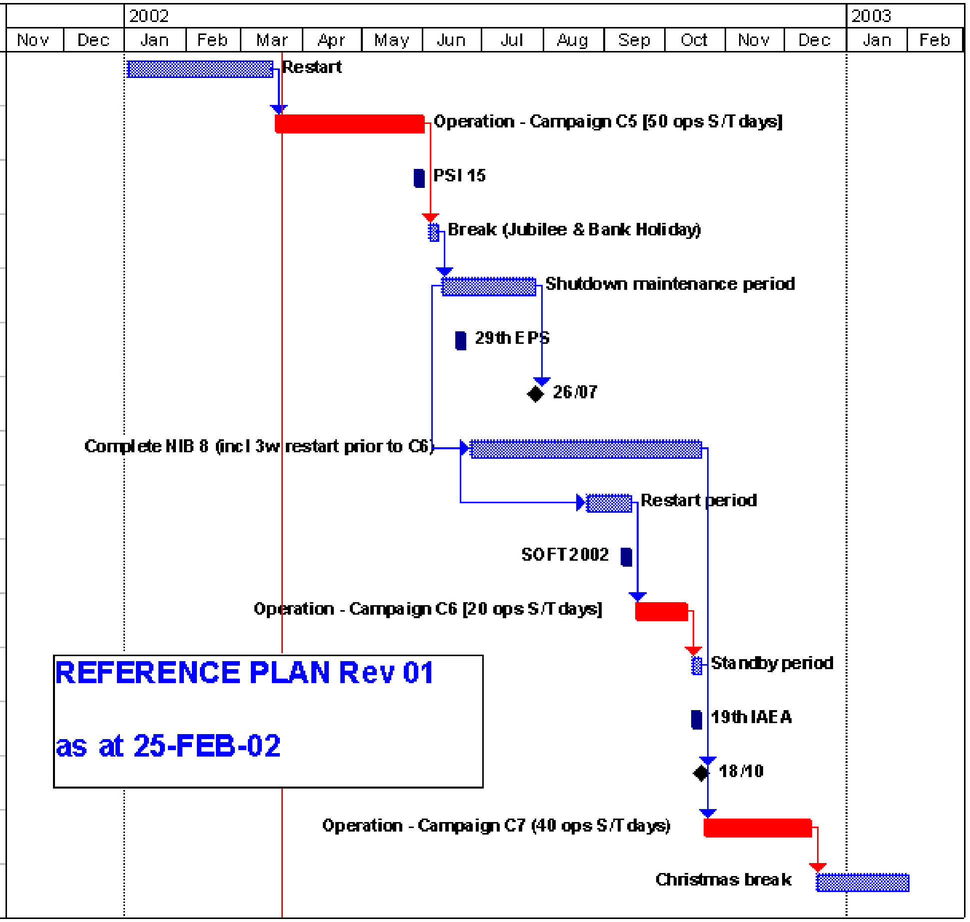
JET Reference Plan 2002

ID	Task Name	Dur	Start	Finish
1	Restart	53 d	02/01/02	15/03/02
2	Operation - Campaign C5 [50 ops S/T days]	52 d	18/03/02	31/05/02
3	PSI 15	5 d	27/05/02	31/05/02
4	Break (Jubilee & Bank Holiday)	5 d	03/06/02	07/06/02
5	Shutdown maintenance period	35 d	10/06/02	26/07/02
6	29th EPS	5 d	17/06/02	21/06/02
7	Torus Hall closed for Operation	0 d	26/07/02	26/07/02
8	Complete NIB 8 (incl 3w restart prior to C6)	85 d	24/06/02	18/10/02
9	Restart period	17 d	22/08/02	13/09/02
10	SOFT 2002	5 d	09/09/02	13/09/02
11	Operation - Campaign C6 [20 ops S/T days]	20 d	16/09/02	11/10/02
12	Standby period	5 d	14/10/02	18/10/02
13	19th IAEA	5 d	14/10/02	18/10/02
14	NIB 8 project completed	0 d	18/10/02	18/10/02
15	Operation - Campaign C7 (40 ops S/T days)	40 d	21/10/02	13/12/02
16	Christmas break	35 d	16/12/02	31/01/03



JET Plan 2002 - 2004

Topics for Experimental Campaigns C5 - C7 (2002)

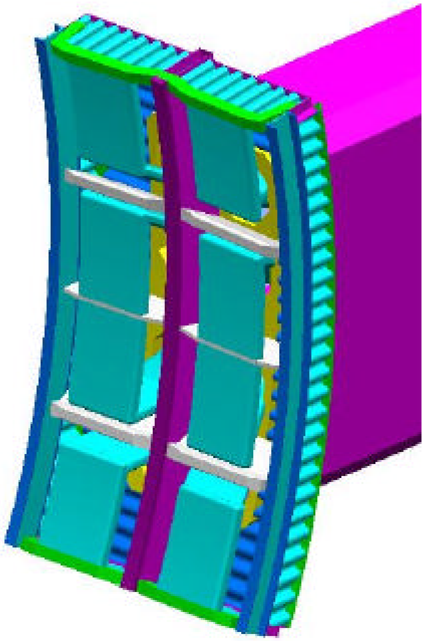
- **Topic 1:** Characterisation of the Mark IIGB Divertor (without Septum)
- **Topic 2:** Core-Edge Integration
- **Topic 3:** ITER Scenarios at High Plasma Current and Power
- **Topic 4:** Steady State Operation including Non-inductive CD&Real Time Control
- **Topic 5:** Confinement of High Density ELMy H-modes
- **Topic 6:** ITB Trigger and Access Conditions
- **Topic 7:** Impurity Confinement
- **Topic 8:** Neoclassical Tearing Modes
- **Topic 9:** Energetic Particles
- **Topic 10:** Disruptions, Runaway Electrons and their Mitigation
- **Topic 11:** Plasma-Wall Interaction and Hydrogen Retention
- **Topic 12:** Role of Externally Injected Rotation on Conf.& MHD Stability
- **Topic 13:** Basic Transport Studies
- **Topic 14:** Basic SOL and Divertor Physics and Scaling of SOL Parameters

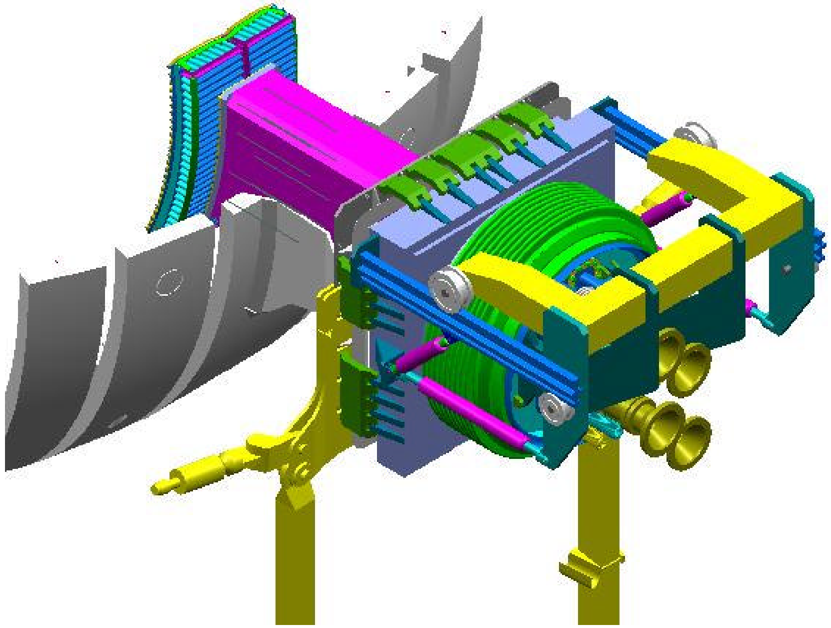
JET Plan 2002 - 2004

- **The 2004 shutdown starting in February 2004 is mainly devoted to:**
  - **Installation and commissioning of the ICRH ITER like antenna**
  - **Installation and commissioning of new diagnostics**
  - **Refurbishment activities including divertor (i.e. load bearing SRP + diagnostics) and magnetics**
  - **Normal maintenance**

The JET ICRH ITER-like antenna

- ELM resilient / high power coupling in ELMy H-mode
- 7.5 MW at ITER relevant coupling (2-4 W/m)
- ITER relevant high power density coupling
- High coupling efficiency (90%) in range 30<f<55 MHz



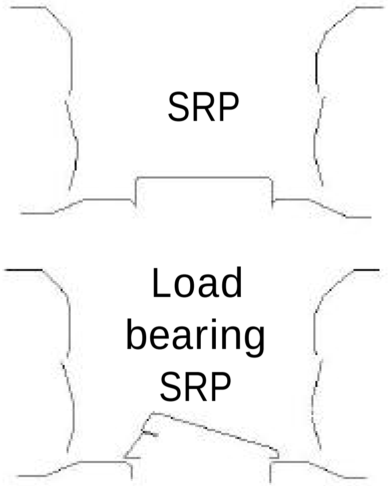


Diagnostics Enhancements Projects 2003-2004

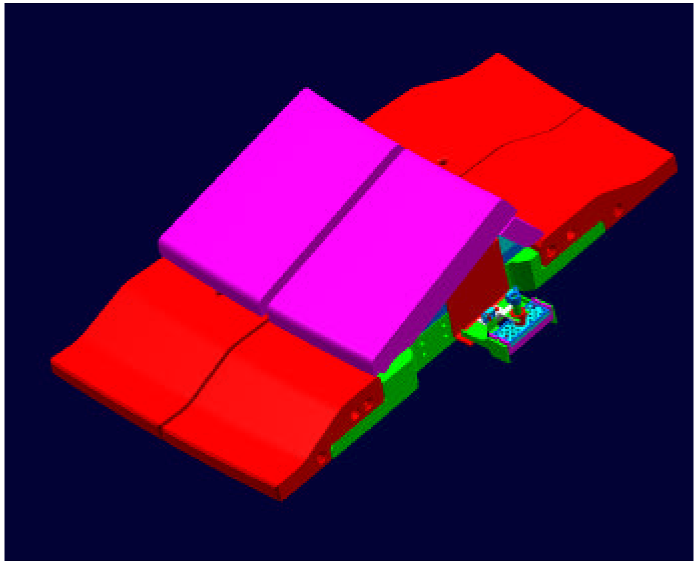
- **Halo sensors and magnetics *(RFX/ENEA*) / ITER relevant**
- **High resolution Thomson Scattering *(RFX, IST, SCK/CEN*) *(US interest to be confirmed, DIII-D)***
- **CXRS core *(UKAEA,SCK/CEN*) *(US interest to be confirmed ORNL)***
- **Microwave access *(IST,CNR-Milano*) / ITER relevant *(US interest to be confirmed PPPL)***
- **Vertical bolometer camera *(IPP tbc, CEA, RFX*)**
- **Tritium retention studies diagnostics *(UKAEA, TEKES, FZJ, IPP*) / ITER relevant**
- **MSE upgrade / edge current *(UKAEA, VR, SCK/CEN*) *(US interest to be confirmed, DIII-D)***
- **IR camera viewing system *(CEA, ENEA tbc*) / ITER relevant**
- **TAE antennae / high n modes *(CRPP*) *(US interest to be confirmed MIT)***
- **MPR *(VR, CNR-Milano, ENEA*)**
- **TOFOR *(VR, CNR-Milano, ENEA*)**
- **Lost alphas *(provided it is fully implemented under international collaboration: US interest to be confirmed, PPPL and Colorado School of Mines)***

The divertor "load bearing" SRP

- "Load bearing" Septum Replacement Plate
- Vertical targets from Mk-II Gas Box Divertor
- Horizontal target modified
- Power handling



  - Asymmetric target plate
  - Optimised for high δ
  - Some refurbishment of diagnostics is possible



Operating Experience and Statistic Analysis

Operation at JET

•Double shifts (6.30-22.00), 5 days per week

Key actors: SL - SC - DC - EiC

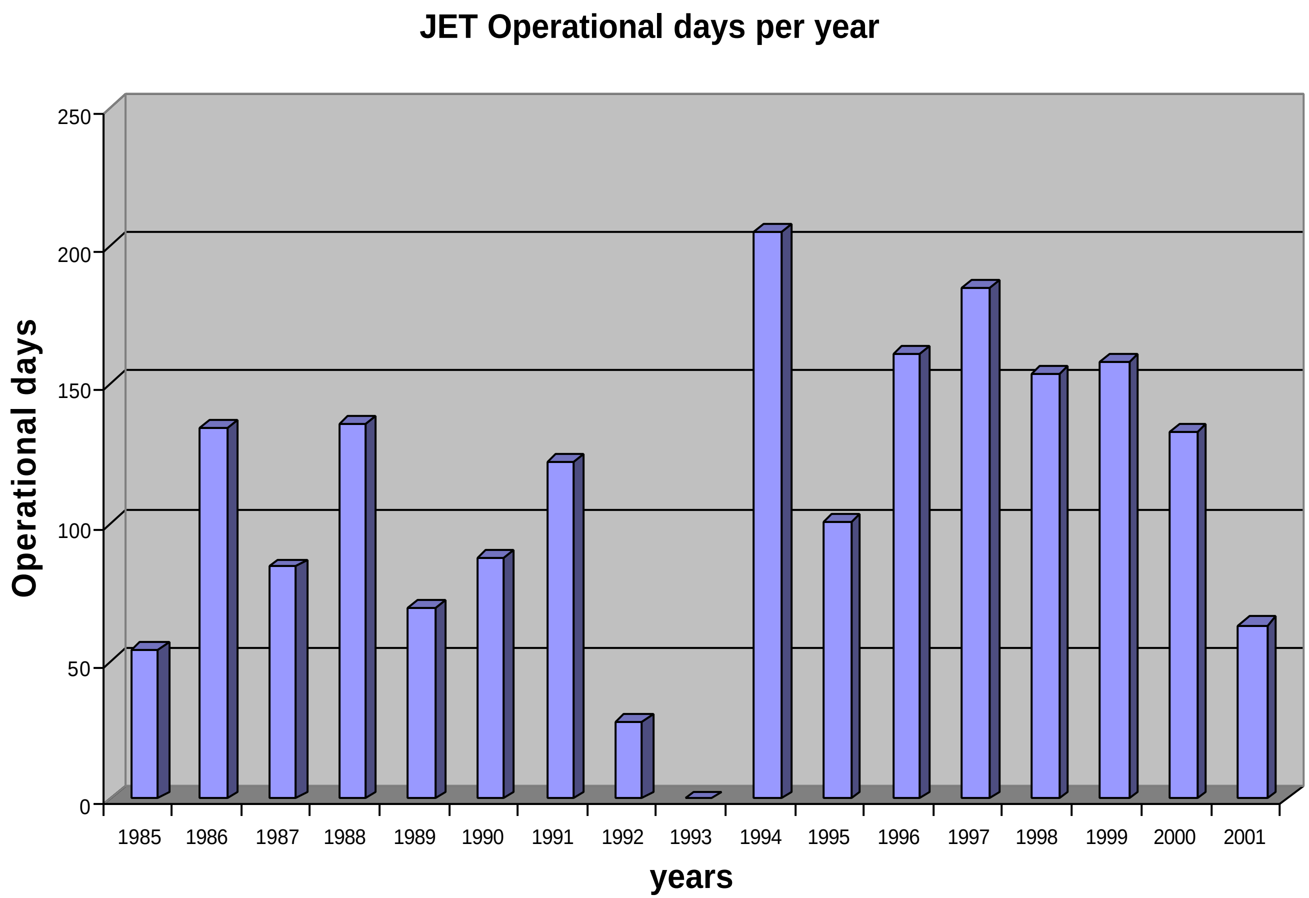
Aim: produce "**good scientific pulses**" for the experimental programme

Increasing the number of "good scientific pulses" has a great value both from the scientific and the economical point of view.

Necessary steps

- reduction of delay time and time between pulses
- increase of "engineering successful pulses" (high availability of systems)
- reliable operation of diagnostics, and good performance of additional heating systems
- optimisation of the preparation and realisation of the sessions

Operating Experience and Statistic Analysis



EUROPEAN FUSION DEVELOPMENT AGREEMENT

Operating Experience and Statistic Analysis

High level technical indicators

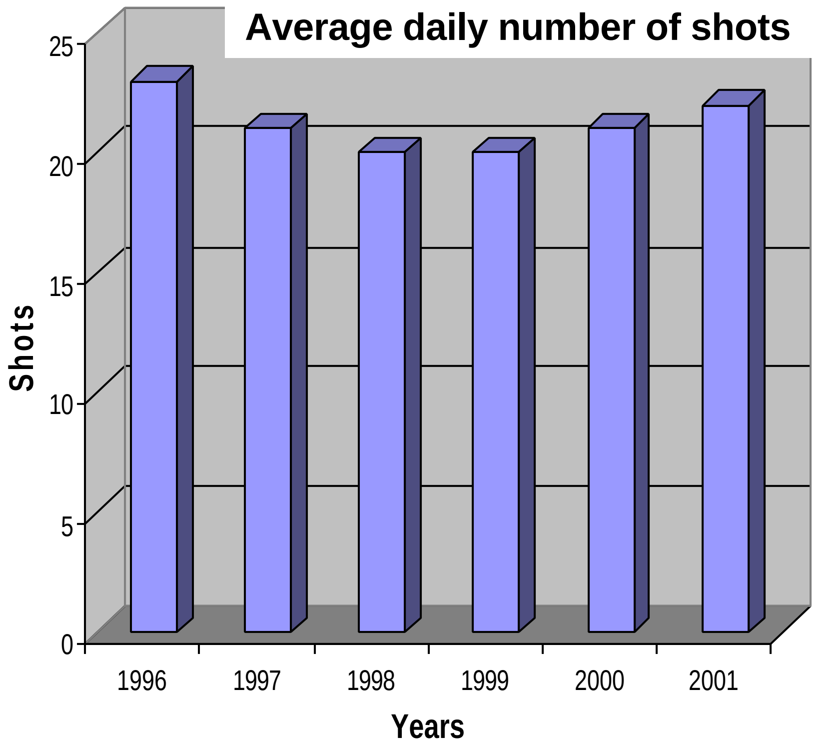
- **Engineering successful Shots: Ratio [Average/day]**
- **Experimental time: Ratio [actual/planned]**
- **Delays: per systems per day**
- **Delays: per subsystems/components per day**
- **Delay: Ratio [per cause/overall]**
- **Additional Heating: Ratio [delivered power/requested power]**
- **Energy: Ratio [Delivered/Requested]**
- **Power: Average total coupled power per pulse**
- **Energy: Average total injected per pulse**
- **Scientific successful pulses: [Average/day]**

EUROPEAN FUSION DEVELOPMENT AGREEMENT

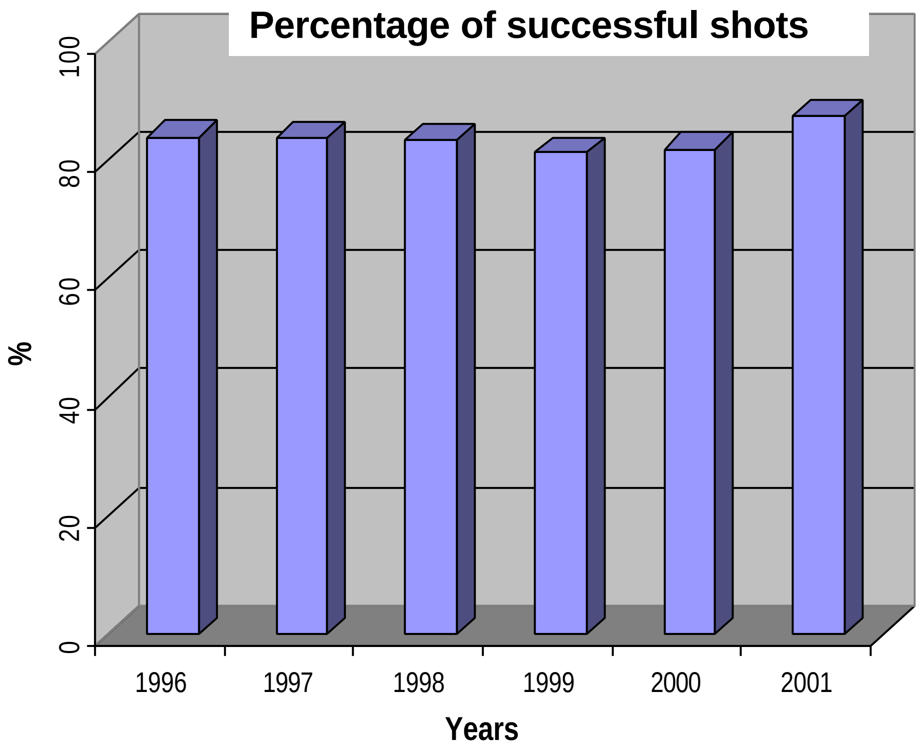
Operating Experience and Statistic Analysis

Average shots per year

Number of shots / day / year



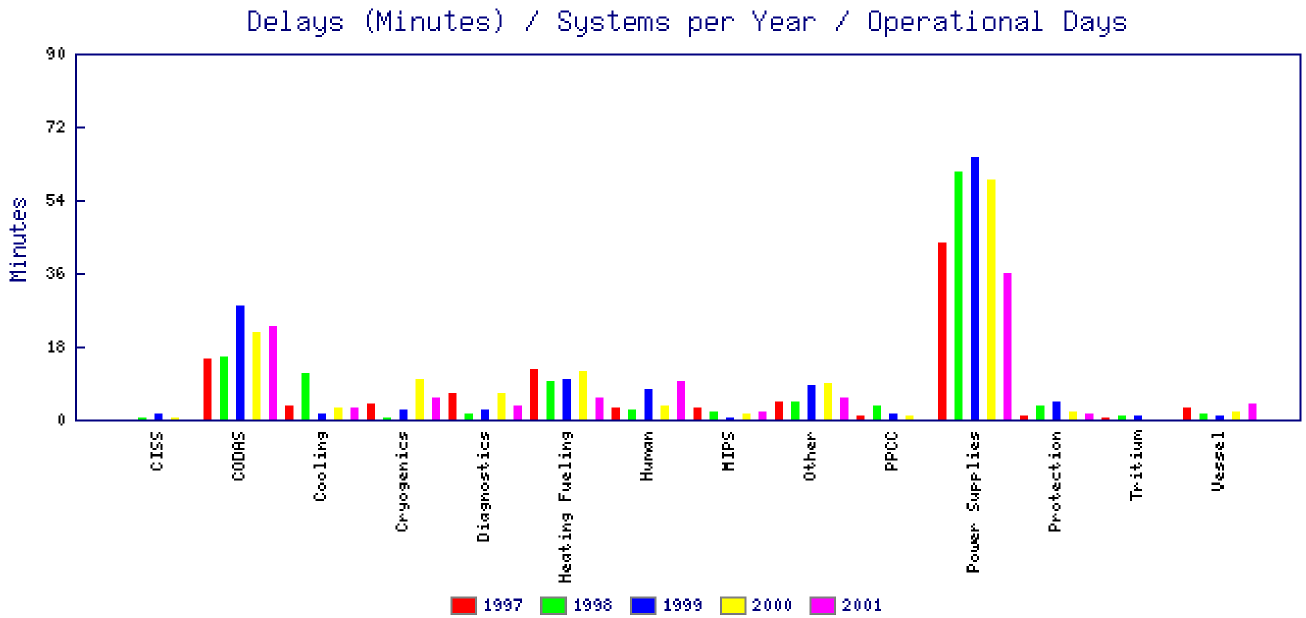
Successful / total shots per year



=> Target for 2002

decrease time between pulses / increase number of useful pulses by 1-2 / day

Operating Experience and Statistic Analysis

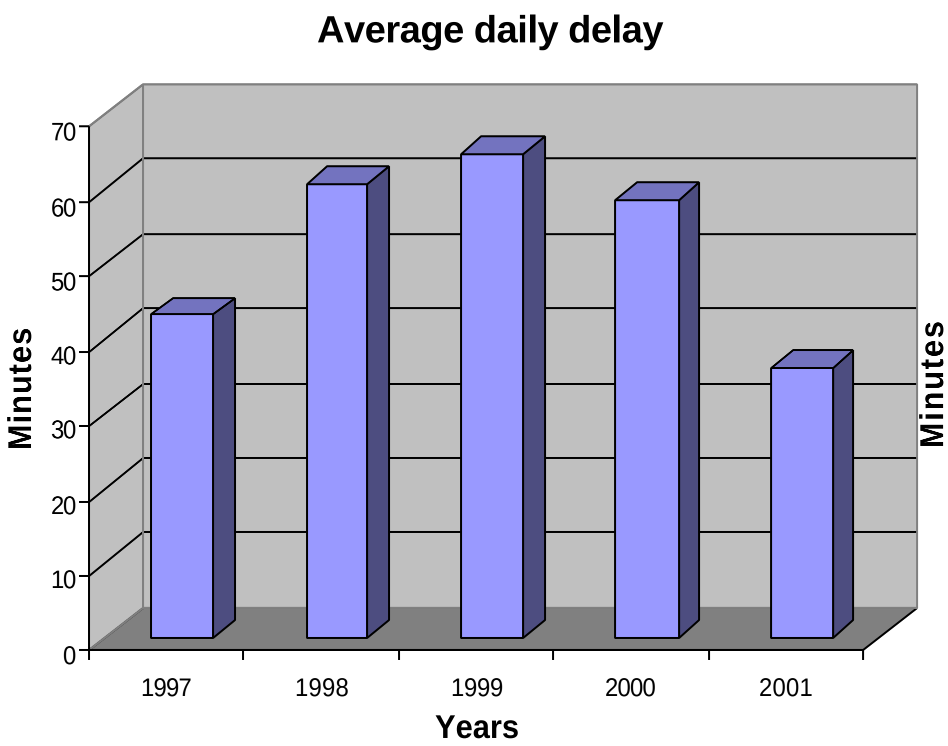


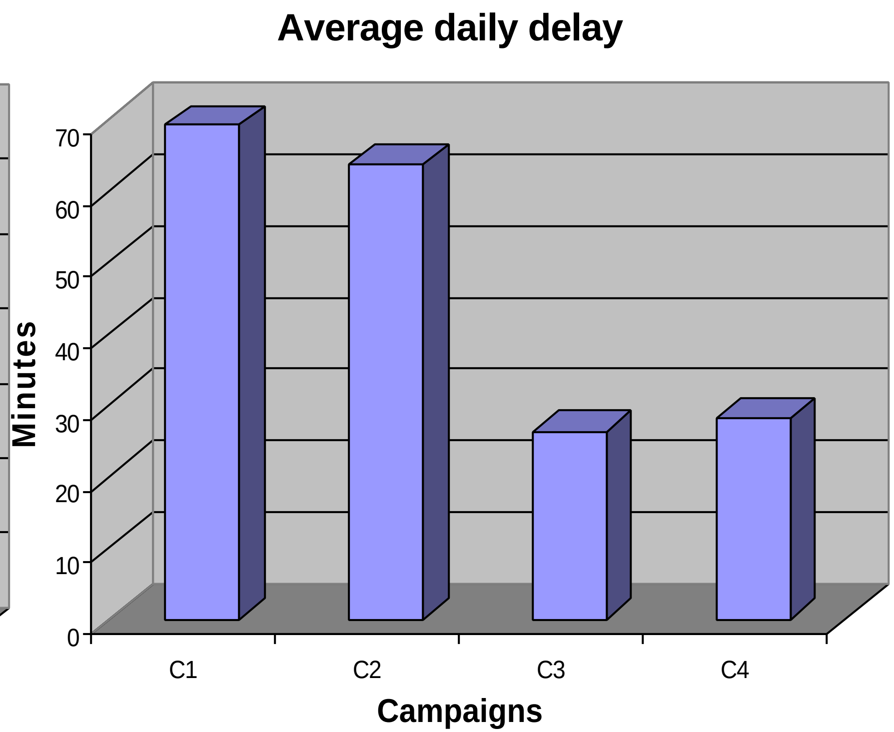
EUROPEAN FUSION DEVELOPMENT AGREEMENT

JET

Operating Experience and Statistic Analysis

Improvement on JET Operation:
e.g. reduction in Power Supply delays





Operating Experience and Statistic Analysis

Improvement of Power Supply Reliability

- **Fault analysis in order to:**
  - Find out what is failing and eliminate it
  - Quantify the degree of deviation from the target
  - Identify potential causative factors for lost time
  - Pointer towards a problem areas
  - Allocate resources effectively

Operating Experience and Statistic Analysis

Improvements made as a result of fault analysis

- **Personnel training** (to recover loss of expertise in 1999)
- **Communications** (procedures and responsibilities)
- **S4s switches** (from MTBF analysis shorter intervals for maintenance)
- **PVFA fuses** (design changes to remove the thermal ageing)
- **NBI magnet cooling system** (shorter access time by adding permanently installed monitors)
- ***NBI Pre-charge protection*** (bypassed as no longer required)
- ***G3 V&I protection*** (interlock to prevent damage and warning to the operator)

Future work on Operating Experience

- **Improvement of data base and its relevant validation**
- **Outcomes from Fusion Technology Tasks at JET**

  1. collection of data from JET main systems 20 years operating experience in view of ITER design and safety analysis.

  2. analysis of the RH activities at JET in view of ITER RH design and manual of operation

Future work on Operating Experience

- **A Working Group has been set up in order to**:
  - Consolidate measures which aim at improving the effectiveness of JET S/T operation (e.g. indicators of technical performances; availability of data between pulses; level of session preparation, co-ordination and assessment)
  - Identify methods of quantifying the effectiveness of JET S/T operation
  - Make recommendations on the scale of improvement which might be achieved realistically during Campaign C7

The main areas under analysis are:

- System reliability-availability: focus on the systems/components responsible for the mayor delays
- Preparation and organisation of the session
- Diagnostics
- Data acquisition and processing

Conclusions

- JET is a unique tool in preparation for ITER operation:
  - Unique worldwide DT and Be capability (including T technology)
  - ITER plasma shape operation in the most relevant range of parameters worldwide
  - Capability of testing ITER diagnostic prototypes in relevant conditions (in particular alpha diagnostics)
  - Operation in all the foreseen ITER plasmas species: He, H D and DT
  - Advanced plasma control capabilities
  - The gap in size and in technical capabilities between JET and other tokamaks (except JT60) is similar to that between ITER and JET
  - Complexity is also an issue for the operation. JET is almost as complex as ITER will be in several systems

Conclusions

- **20 years of Operating experience on systems and components at JET constitute an essential reference for ITER.**
- **Further work is necessary in some areas to validate and make available the relevant information.** (With this aim some Fusion Technology tasks at JET have been launched recently)
- **JET Operation under EFDA is organised as "user facility": each important phase (operation, shutdown, restart) is targeted and monitored**

Conclusions

- **Transition from JET Joint Undertaking to EFDA has been successful**
  - **The results are already matching or exceeding historical performance level (e.g. successful pulses per day)**
  - **There is a strong will among the various Actors (Operator, Associates, EFDA CSU, TFLs) for more scientific successful pulses per day**

Big challenge taking into account:

- **age of components and systems**
- **perspectives (short-medium term programme)**